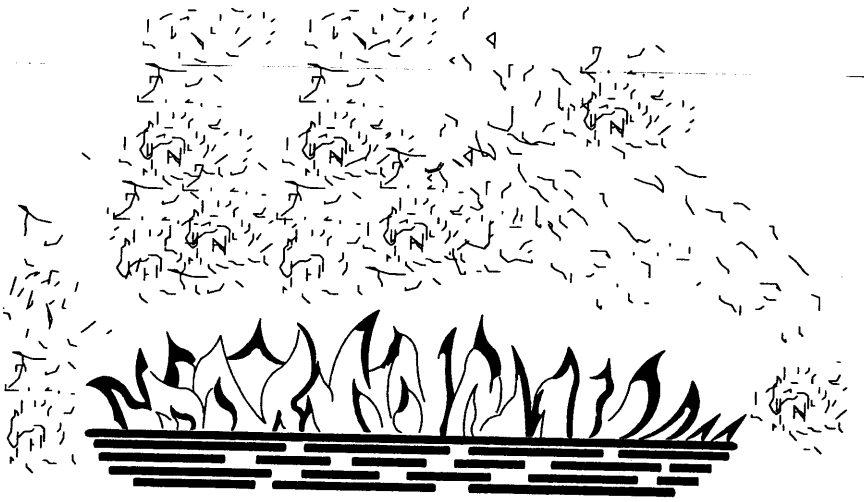
INSTITUT DE RADIOPROTECTION ET DE SURETE NUCLEAIRE
DEPARTEMENT DE RECHERCHES EN SECURITE



	RÉDACTION	VÉRIFICATION	QUALITÉ	APPROBATION
NOM	E. Bouton	C. Casselman	P. SOUSSAN	R. Gonzalez
DATE	14/05/2002	18/06/2002	21/06/02	25/06/02
VISA				
REV. A				
REV. B				

Titre	Overview of the FLAMME_S code validation matrix
Auteur(s)	E. Bouton
Type : NT	Numéro : SESHP/GME/IPS/FLS/C40/NT/02.337

Service d'Essais de Sûreté Hors Pile
Groupe Modélisation et Etudes des Feux

IRSN/DRS/SESHP/GMEF

Cadarache, le 25/06/2002

SESHP/GME/IPS/FLS/C40/NT/02.337

Overview of the FLAMME_S code validation matrix

E. Bouton

SERVICE D'ESSAIS DE SURETE HORS PILE Groupe Modélisation et Etudes des Feux		
Nat. Document	NT	
TITRE	**Overview of the FLAMME_S code validation matrix**	
Auteur(s)	E. Bouton	
Type de diffusion : Normale	"Mots clés" :	Nbre de pages : 199 Nbre de figures : 3

RESUME :
Ce document présente une vue d'ensemble de la matrice de qualification du code FLAMME_S.

ABSTRACT :
This document is an overview of the validation matrix of the FLAMME_S code.

Repère bureautique : SESHP/GME/IPS/FLS/C40/NT/02.337

BP 3 – Bâtiment 346 – 13115 SAINT PAUL LEZ DURANCE
☎ : 04 42 25 31 77 - Fax : 04 42 25 48 74

Siège social : 77-83, avenue du Général de Gaulle – 92140 CLAMART –
Standard : (33) 01 46 54 88 88 – RCS Nanterre B 440 546 018

Table

List of tables

List of figures

1 INTRODUCTION

This note has been written in the framework of the International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications organized by the NRC. Its aim is to give to the participants or the FLAMME_S users an overview of the validation matrix of the code. Therefore, in this document, only the FLAMME_S major features and the test conditions are described. More detailed information can be found in the references, mostly written in French and not open to release.

2 OVERVIEW OF THE FLAMME_S CODE

The FLAMME_S code was developed to compute the consequences of a fire in nuclear power plants or in industrial facilities. This code is based upon a classical two zones model and it can be applied to a single or a multi-room configuration. The main characteristics of the FLAMME_S code are :

- The flame and the plume above the fire pool are described with the empirical correlations set by Heskestad. The Mac Caffrey's plume model is currently under development.
- The calculation of the radiative exchanges inside the room (on walls and on targets) due to the flame relies on a classical point source approach.
- The heat loss of the gases through the walls by conduction is taken into account and can induce the heating of the gases of a target room near the fire room.
- The rooms of the facility can be connected with a ventilation system (at a constant or variable flow rate) or with vertical vents like doors.
- No ceiling jet or horizontal vent models are available.

FLAMME_S can be used autonomously or coupled with the SIMEVENT code devoted to the calculation of flow rates in complex ventilation networks. But the description of this ventilation code is beyond the scope of this paper.

3 VALIDATION DOMAIN

The objective of the validation process of the FLAMME_S code is to evaluate the calculation results for several different configurations, in terms of :

- the room's number of the facility (up to 3 rooms),
- the location of the pool fire (in the middle of the room or against a wall),
- the ventilation conditions (forced or natural),
- the kind of fuels used.

All the tests series considered in the validation matrix are listed in the following table :

Configuration	Location of the pool fire	Test series	Number of tests
Single room	In the middle of the room	LIC, LPI, PEPSI	13
Single room	Against a wall	FLIP	5
Multi rooms	In the middle of the room	Cooper	19
Multi rooms	Against a wall	Peacock	7

Table 1 : List of the test series considered in the validation matrix

Additional information about the test conditions is indicated below or may be found in the references. Furthermore a "rough" criteria, the relative error, has been used to evaluate the quality of the agreement between calculations and test results. When the relative error is less than 20 %, FLAMME_S can be used with confidence for similar calculation conditions. All the tests listed in this document satisfy this condition, except some Peacock's test (See § 3.3.2).

3.1 Fuel used during the test

The different kind of fuel used during the tests are indicated in the following table.

Fuel	Chemical formula	Test
TPH	$C_{12}H_{26}$	LIC2.CB
70% TPH - 30% TBP	70% ($C_{12}H_{26}$) – 30% ($C_{12}H_{27}O_4P$)	LIC/FLIP
Ethanol	$C_2H_6O_1$	LIC1.14/FLIP
Mineral Oil (DTE medium)	$C_{31,34}H_{63,9}$	LPI
Domestic fuel	$C_{15,55}H_{29,3}$	LPI13
Methane	CH_4	Cooper
Methane/acetylene		Peacock

Table 2 : List of fuels

TPH : Hydrogened Tetra Propylen

TBP : Tri Butyl Phosphat

More detailed characteristics of the fuel are given in annexe.

3.2 Single room tests performed at IRSN

3.2.1 Centred fire pool

The different tests achieved with the fire pool in the middle of the room [5], [6] are indicated in the table below.

Area of the pool (m^2)	Fuel	Facility (Volume m^3) (L×l×H) ou (S×H) (wall material)	Ventilation conditions	Test
0,0314	Mineral oil (DTE medium)	4,35 m^3 (0,856 m^2×5,35 m) (steel wall)	confined	LPI 7
0,0314	Mineral oil (DTE medium)	4,5 m^3 (2,011 m^2×2,24 m) (steel wall)	confined	LPI 9bis

0,0629	Mineral oil (DTE medium)	4,5 m^3 (2,011 m^2×2,24 m) (steel wall)	confined	LPI 10
1	70% TPH - 30% TBP	400 m^3 (9 m×6 m×7,6 m) (concrete wall)	mechanical (3 V/H)[1]	LIC 2.3
1	70% TPH - 30% TBP	2000 m^3 (10 m×10 m×20 m) (concrete wall)	Natural	LIC 2.8.1
1	70% TPH - 30% TBP	3600 m^3 (20 m×15 m×12 m) (concrete wall)	confined	LIC 2.CA
1	TPH	3600 m^3 (20 m×15 m×12 m) (concrete wall)	confined	LIC 2.CB
1	Mineral oil (DTE medium)	400 m^3 (9 m×6 m×7,6 m) (concrete wall)	mechanical (5 V/H)	LPI 11A LPI 11 PEPSI 1
1	ethanol	400 m^3 (9 m×6 m×7,6 m) (concrete wall)	mechanical (5 V/H)	LIC 1.14
2	Mineral oil (DTE medium)	400 m^3 (9 m×6 m×7,6 m) (concrete wall)	mechanical (5 V/H)	LPI 12
5	70% TPH - 30% TBP	2000 m^3 (10 m×10 m×20 m) (concrete wall)	Natural	LIC 2.8.5
5	Mineral oil (DTE medium)	2000 m^3 (10 m×10 m×20 m) (concrete wall)	Natural	LPI 13
5	Domestic fuel	2000 m^3 (10 m×10 m×20 m) (concrete wall)	Natural	LPI 19

Table 3 : List of IRSN tests (centred fire)

3.2.2 Fire pool against a wall

In the FLIP tests [1], [8], the fire pool was located against the south wall of the PLUTON facility (V = 400 m^3, l×w×h 9 m×6 m×7,6 m). In this facility, all the walls are made of concrete except the south wall which was covered with a thermal insulating material made of thermipan. Whatever the test considered, the steady ventilation flow rate before the onset

of the fire was 3 volume changes per hour. The squared inlet (0.5 x 0.6 m^2) is located in the bottom and in the middle of the north wall ; the squared outlet (0.5 x 0.8 m^2) is in the top and in the middle of the west wall (cf. Figure 1).

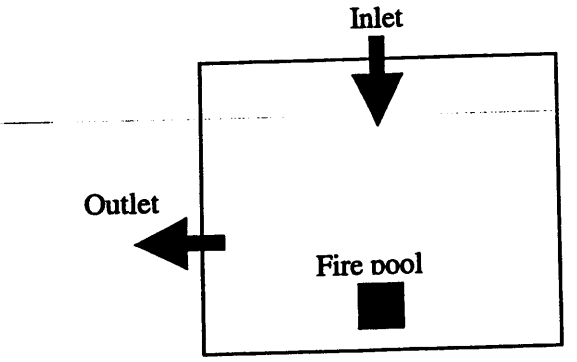


Figure 1: overview of the PLUTON facility

Additional information about the FLIP test is listed below :

Area of the pool (m^2)	Kind of fuel	Q (kW)	Test
0.4	TBP/TPH	360	FLIP1
0.4	Ethanol	215	FLIP1A
1.0	TBP/TPH	645	FLIP2
1.0	Ethanol	510	FLIP2A
1.5	TBP/TPH	910	FLIP7

Table 4 : List of IRSN FLIP test (fire pool against a wall)

Remark : Q is the average heat release rate (kW)

3.3 Multi-room tests

The FLAMME_S code was validated in multi-room configurations by using the tests performed by Cooper [4], [9], [10] and Peacock [7], [2], [3].

3.3.1 Cooper tests

The facility used by Cooper has 2 or 3 rooms, with a variable length for the corridor. The surface of the total floor is in the range of 40.6 m^2 to 89.6 m^2.

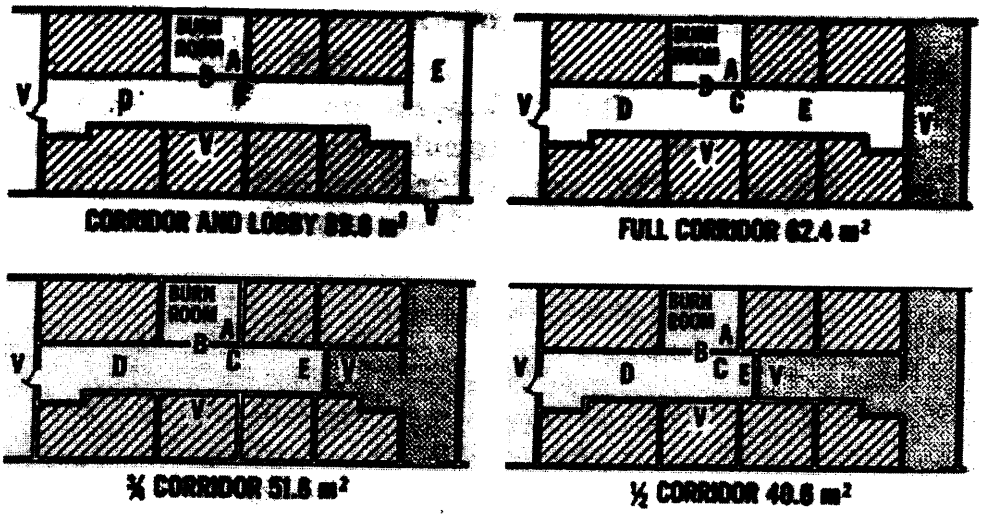


Figure 2 : Overview of the Cooper facility

A square gas burner (0.3 x 0.3 m^2) is set in the middle of a room and is supplied with methane. In the tests, the fire duration does not exceed 10 mn. The steady heat release rate of the fire (Q) is 25, 100 or 250 kW. The growth of the fire is modeled as :

$$Q(t) = 30\,t \quad \text{with} \quad 0 < t < 10 \text{ mn} \quad (Q \text{ in kW})$$

The other test conditions are listed in the following table :

Q (kW)	½ corridor	¾ corridor	corridor	Corridor and lobby	Corridor 1/2 door	Corridor 1/4 door	Corridor 1/8 door
25	x	x	x	x			
100	x	x	x	x	x	x	x
225	x	x	x	x			
Ramp fire	x	x	x	x			

Table 5 : List of Cooper tests

3.3.2 Peacock tests

An overview of the facility used by Peacock is displayed on the following scheme. It is composed of two or three rooms connected by doors.

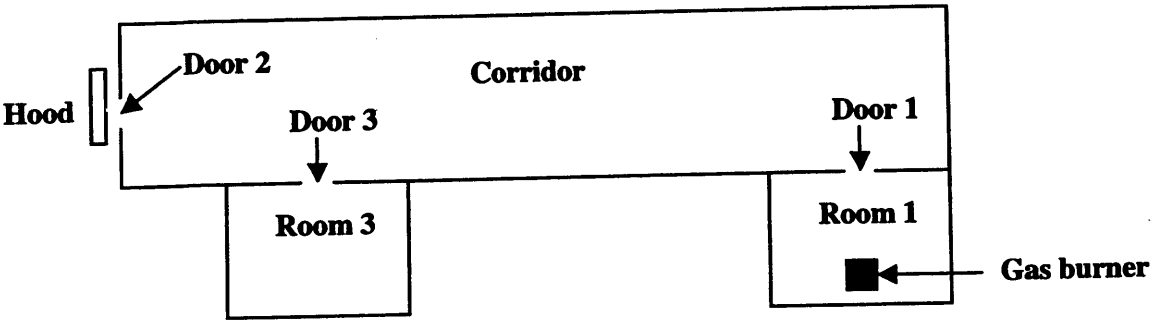


Figure 3 : Overview of the Peacock facility

The burn room walls are made of ceramic fiber and those of the second and third room are covered by gypsum board. Furthermore, the room dimensions are indicated in the following table :

Room	Length (m) x width (m) x height (m) Volume (m^3)
1	2.34 x 2.34 x 2.16 (11.83 m^3)
2	12.19 x 2.44 x 2.44 (72.6 m^3)
3	2.22 x 2.24 x 2.43 (12.1 m^3)

Table 6 : Room dimensions of Peacock's facility

A gas burner is set against a wall of the first room. The fuel is a gas mixture made of methane and acetylene. The heat release rate of the fire (HRR) is varied in the range of 100 to 500 kW. The combustion products are collected by a hood located just behind the second door. By using the O_2 consumption method, the HRR of the fire is deduced from hood measurements and not directly recorded with a weight device. This is the main difference with the other tests performed and listed in the validation matrix.

The conditions of the Peacock's tests are summed up in the table below :

Test number	Q (kW)	Door (corridor)	Third room
1	100	Open	No
4	100	Open	Yes
5	300	Open	No
6	300	Closed	Yes
7	300	Open	Yes
8	500	Open	No
9	500	Open	Yes

Table 7 : List of Peacock's tests

Concerning these tests, some restrictions about the agreement between calculations and test results must be made. Whatever the test considered, the average room temperature is well estimated ; the maximum value reached in the fire room in the case of the 500 kW heat released rate is very high around 550 °C. The flow rates through the door connecting the fire room to the corridor is also in good agreement with measurements. This is not true for the other doors of the facility probably due to the uncertainty on measurements. Furthermore, the upper layer temperature is enough over-estimated and the lower layer temperature under-estimated ; for these variables the relative error is beyond 20 % criteria.

4 CONCLUSION

Some general remarks can be drawn from the validation process about the limitations and the validation domain of the code. The upper layer temperature (resp. the lower layer temperature) is generally over-estimated (resp. under-estimated) even if the agreement between calculations and measurements is good. Given a facility and a forced ventilation flow rate before the start of the fire, the accuracy of the calculation deereases as a function of the heat release rate of the fire. These results are in agreement with the literature and not limited to the FLAMME_S code. They are likely link to the two zone approach.

Given the previous limitations, the FLAMME_S code is well validated over a large range of test conditions derived from the literature or from experiments performed at IRSN (more details of the tests used are given below). The main results of the comparison between the calculations and the experiments are the following :

1/ The relative error is less than 20 percents for the main thermodynamical parameters like the pressure in the room, the oxygen concentration and temperature in each layer, the average temperature of the wall and the ventilation flow rate, except in some Peacock tests (See § 3.3.2).

2/ The FLAMME_S code is validated for single room configurations (18 IRSN tests) and for multi-room configuration (19 tests performed by Cooper and 7 experiments achieved by Peacock).

Therefore the FLAMME_S code can be used with confidence in the following conditions :

- The room walls are made of concrete or of steel.
- The height of the room is equal or greater than the smallest horizontal dimension of the room.
- The room is sealed or connected to the outside with vertical openings or with a ventilation network (the flow rate is in the range of 3 to 5 volume changes per hour before the start of the fire).
- The fire pool is set in the middle of the room or against a wall.
- The fuel is a gas or made of mineral oil or of an organic liquid.
- The ratio of the pool area to the area of the floor of the facility is less than 5 percents.

- The pyrolysis rate of the fuel is an input data.
- The ratio of the heat release rate to the volume of the facility is less than 5kW/m^3.

In the next future, new validation exercises are planned. FLAMME_S will be used to simulate the results obtained in a multi-room configurations with natural and mechanical ventilation (DIVA tests).

5 REFERENCES

[1] **Bouton E., (1999),** "Qualification du code FLAMME_S (v2.3) dans le cadre de la 1ère série d'essais de feux de liquides en interaction avec une paroi", SESHP/GME/IPS/FLS/C40/RA-99.1332.

[2] **Bouton E., (2000),** "Qualification du code FLAMME_S en configuration multilocal Essais Peacock : Etude préliminaire", IRSN/DRS/SESHP/GME/IPS/FLS/C50/RP-01.797.

[3] **Bouton E., (2001),** "Essai Peacock et Al (1988) – Etude de qualification du code FLAMME_S (Contrat EURIWARE n° 4020 2 0B043220 – lot 2)", SESHP/GME/IPS/FLS/C50/RP-01.836.

[4] **Cooper L. Y., Harkleroad M., Quintiere J., Rinkinen W., (1982),** "An experimental study of upper hot layer stratification in full-scale multi-room fire scenarios", Journal of Heat Tranfer, Vol. 104, pp 741-749, 1982.

[5] **Malamas M., (2000),** "Logiciel FLAMME_S Version 2.3 Notice de qualification", SESHP/GME/IPS/FLS/C40/RA/00.115, Contrat n°4020 28COR0180.

[6] **Malamas M., (2000),** "Logiciel FLAMME_S Version 2.3 Rapport de qualification", FLAMME_S_99/NT/006, Contrat n°4020 28COR0180.

[7] **Peacock R. D., Standford D., Billy T. L. (1988),** " An Experimental Data Set for the Accuracy Assessment of Room Fire models", National Bureau of Standards, Gaitherburg, MD 20899, NBSIR 88-3752.

[8] **Pernot B., (2000),** "Qualification du code FLAMME_S / SIMEVENT à partir des essais FLIP", GME/IPS/FLS//RP/01.0361.

[9] **Tourniaire B., (1998),** "Etude bibliographique d'essais de feux à grande échelle en configuration multilocal", SESHP/GMEF/n°EF.30.40.R/98.414.

[10] **Tourniaire B., (1998),** "Qualification du code FLAMME_S v2.3 en configuration multilocal : 1ère partie – Essais de Copper, Harkleroad, Quintiere et Rinkinen", SESHP/GMEF/n°EF.30.40.R/98.1234.

Remark :

Reports written in French are the IRSN's property and not open to release.

ANNEXE1 : CHARACTERISTICS OF THE FUELS

Legend :

M : molar mass

PCI : standard heat of combustion (MJ/kg)

χ_r : heat fraction released by the flame as radiation

ρ : density

Kind of fuel	M (g/mol)	PCI (MJ/kg)	χ_r	ρ (kg/m^3)	Test
Ethanol	46	25.6	0.25	794	FLIP
	46	26.78	0.25	794	LIC1.14
TBP/TPH	195.25	36	0.35	836	FLIP
	195.25	40	0.35	816.8	LIC2.3 LIC2CA
	195.25	32	0.35	816.8	LIC2.8.1 LIC2.8.5
Mineral Oil	439.98	41.86	0.35	870	LPI PEPSI
Domestic fuel	215.9	40	0.35	840	LPI19
TPH	170	40	0.35	749	LIC2CB
Methane	16	55	0.24	/	Cooper
Methane/actetylene	20.96	46.54	0.25	/	Peacock

ANNEXE 2 : CHEMICAL REACTIONS

In the validation process, the combustion products are composed by H_2O, O_5P_2, CO_2, C and the chemical reaction is written in the following way :

$$C_aH_bO_cP_d + \delta[O_2 + 3.7742N_2] \rightarrow b/2H_2O + d/2O_5P_2 + \alpha CO_2 + \beta C$$

It is possible to compute the mole number of each product with the following assumptions :

- Every hydrogen atom is combined with oxygen to product water,
- Phosphor atoms in the fuel form O_5P_2,
- The mass fraction of soot to mass of burnt fuel is p.

Given these assumptions, the different mole numbers are written as :

$$\alpha = a - (p/100)M_{fuel}/M_{soot} \qquad \beta = (p/100)M_{fuel}/M_{soot} \qquad \delta = 0.5\,[b/2 + (5/2)d + 2\alpha - c]$$

TBP/TPH

Test	O_2	CO_2	C	p (%)
LIC23	18.298	11.929	0.071	10*
LIC2.8.1	16.02	9.651	2.349	24*
LIC2.c.a	16.107	9.738	2.262	13.9
LIC2.8.5	16.042	9.673	2.327	14.3
FLIP	16.091	9.722	2.278	14

$$*\beta = (p/100)\,M_{fuel}/M_{soot} - (d/2)\,M_{O5P2}/M_{soot}$$

Mineral oil

Test	O_2	CO_2	C	p (%)
LPI7	43.905	27.93	3.41	9.3
LPI9bis	43.282	27.307	4.033	11
LPI10	44.125	28.15	3.19	8.7
LPI11A LPI11 LPI12 LPI13	45.738	29.763	1.577	4.3
PEPSI	44.525	28.55	2.79	7.62

Other fuels

Fuel	O_2	CO_2	C	p (%)
Domestic fuel	20.356	13.031	2.519	14
TPH	17.083	10.583	1.417	10
Methane	2	1	0	0
Methane/acetylene	2.428	1.329	0.046	2.63